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Method for quality assurance of screw joint tightening.

The invention relates to a method for assuring the quality of screw joint tightening processes where screw joints are tightened to a needed pretension condition, a needed clamp force in particular, by means of a torque delivering power tool.

When tightening screw joints, especially the typical screw joints of the motor vehicle industry and similar volume production, a homogeneous and well defined clamp force is the target in a majority of the applications. Various methods have been developed to control the clamp force by the indirect means of torque, angle and time measurements, i.e. the measurable parameters of a typical screw joint tightening. During the design phases of a screw joint theoretical calculations complemented with full scale tests or simulations help to decide which tightening method should be used.

A modern screw joint tightening system, like the PowerMACS-system marketed by Atlas Copco, comprises one or more electric nutrunner spindles, and a monitoring and control system including a process computer or system intelligence. Each nutrunner spindle is equipped with one or two torque transducers and one or two angle encoders. The system measures the motor current and the motor speed in various ways.

Various methods have been developed for controlling, or eliminating to the largest possible extent, the negative influence of the friction between thread and contact surfaces, screw geometry and material properties. All these methods are based on software algorithms which form part of the controller programs and make it possible to control and compensate for most of the encountered variations in the production process.

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A simulation program is used in the above mentioned screw joint tightening system, PowerMACS, for simulating production results assuming certain hardware, joint characteristics and variable input parameters and using the same software parameters as used in the actual screw joint tightening performed by the Power MACS. The results of the simulations are reported as production statistics normally evaluated by the QA-engineers of the industry. With the representative screw joint data, system hardware and software the simulation program has the advantage of being able to calculate also the screw joint clamp force which is the most wanted information. Under production conditions information of the achieved clamp force is obtainable indirectly only, which is a shortcoming.

The main object of the invention is to obtain reliable information on tightening results by combining data resulting from the actual production with simulated results based on various parameters, whereby inter alia information of the clamp force may be continuously reported.

The most important input parameters used in the simulation procedure are the screw joint characteristics, including the torque-angle gradient which is a fairly good definition of the combined characteristics of the screw and the elements being clamped. A continuous calculation of the torque-angle gradient elevates the tightening results reporting to a higher level.

The method according to the invention also makes it possible not only to report of installed torque and angle, but is able to continuously report of torque rate values and certain statistics like Cpk (capability index for the system). It also allows for reporting of a continuously simulated clamp force as well as warnings for changed surface treatments and friction conditions of the screw

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joint etc. The reporting may also contain not only graphs showing typical torque-angle or torque-time curves but clamp force vs. angle and/or clamp force vs. time.

The new method means an improvement as regards understanding of the production and for suggestions of what kind of improvements of the tightening process that can be achieved.

The invention is described below in further detail with reference to the accompanying drawings in which Fig.1 shows a flow chart of progressive reporting of a tightening process according to the invention. Fig.2 shows a diagram illustrating the relationship between tightening torque and loosening torque.

It all starts at the top of the flow chart with the basic design of the screw joint intended for the actual clamping of two or more elements, including the design of the elements themselves. The purpose of the screw joint is to accomplish a certain pretension condition or needed clamp force  $F_N$ .

In a second step, a simulation of a tightening process is performed, wherein details of the screw joint like screw geometry and surface treatment are chosen, as is the type of power tool to be used and which tightening method should be applied. Also tightening parameters like torque level, angle of rotation and/or time interval are chosen on empirical grounds. The simulation comprises a number of simulated tightening processes based on randomly chosen parameter values within the deviation limits or tolerances of each parameter. The result is presented by the simulation program as a mean value and a scattering interval of the obtained clamp force, torque, angle and torque rate, i.e. torque growth per angle of rotation.

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In a third step, the resultant simulated clamp force  $F_s$  is compared to the needed clamp force  $F_N$ , and in case the result is outside certain tolerance limits a new simulation is performed with adjusted parameter values. This is repeated until an acceptable result is obtained where the obtained clamp force is within the tolerances for the needed clamp force  $F_N$ . From the simulation process there is obtained the parameter values of torque and angle as well as the torque rate.

In a fourth step, the parameter values used in the accepted tightening simulation process are applied in the control program of the screw tightening equipment for the practical production tightening.

In a fifth step, the production screw joint tightening is performed, and the resultant parameter values of torque  $T_{ACT}$ , angle of rotation  $A_{ACT}$ , torque rate  $TR_{ACT}$  are compared with the simulated values and tolerance limits. Should the production values be outside the tolerance limits established by the simulated tightening the production is either stopped with reports of deviation or continued with alarm and reports of deviations.

Should in a sixth step the production still result in deviations outside the simulated tolerance limits established by the simulation process the screw joint may be conditioned for obtaining a lower/less scattering friction, and/or the production control program is calibrated with respect to the deviations in the tightening parameters. This may result in a second stop and report procedure where the alternative alerts are: alarm + continued production, alarm + production stop, reporting geometry deviations, or reporting surface deviations.

In calibrating the friction the screw joint is tightened and loosened while the torque and angle values are

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registered and the torque - angle relationship is calculated in both directions. The torque is function of both the friction and the geometric features of the joint, like the thread pitch and the elasticity of the joint, and in the tightening direction the pitch and elasticity co-operate with the friction to build up a torque resistance. In the loosening direction, the friction still causes torque resistance whereas the geometry "helps" the nutrunner to turn the joint. This means that  $T_{\text{tight}} = k A + cA$ , whereof  $k$  is influenced by friction and  $c$  is influenced by the geometry of the joint. See Fig. 2. When loosening the joint applies:  $T_{\text{loos}} = kA - cA$ .

The respective gradients are:  $dT_{\text{tight}}/dA = k + c$ , and  $dT_{\text{loos}}/dA = k - c$ .

Accordingly:  $k = \frac{1}{2} (dT_{\text{tight}}/dA + dT_{\text{loos}}/dA) \rightarrow k_{\text{mean}}; \rightarrow k_{\text{dev}}$   
 $c = \frac{1}{2} (dT_{\text{tight}}/dA - dT_{\text{loos}}/dA) \rightarrow c_{\text{mean}}; \rightarrow c_{\text{dev}}$

Various SPC techniques may be used to warn for deviations from expected values.

If  $k_{\text{mean}} > k_{\text{limit}}$  there are surface and/or lubrication deficiencies.

If  $c_{\text{mean}} > c_{\text{limit}}$  there are geometrical disturbances.

This is a way of determining the coefficient of friction, and whether the coefficient of friction is within normal deviation limits. If it is not the reason for deviations must be due to geometrical deficiencies in the screw joint. Accordingly, it is possible to determine whether it is a friction based deviation or a geometric ground for end result deviations. If changes have to be done to avoid faults in surface treatments or the design of the joint, new simulations have to take place.